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AD NUMBER
AD837138
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OCRD ltr 14 Jul 1972

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THE APPLICATION OF THE SCIENTIFIC METHOD IN ANALYZING THE MAN/WEAPON COMBINATION IN A COMBAT TEST ENVIRONMENT

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This paper deals with the application of operations research and systems analysis techniques to a test methodology study (COMBATEST) being conducted by the Infantry Board--a subordinate testing agency of the US Army Test and Evaluation Command, Aberdeen Proving Ground, Maryland.

The mission of the Infantry Board is to test and evaluate military equipment for the Army--with emphasis on that equipment which is designed for the infantryman. Since the Board tests equipment which will be used in combat, it conducts tests under conditions representing as nearly as possible those combat conditions soldiers may expect to find on the battlefield.

In 1964, the Commanding General of Test and Evaluation Command wrote a letter to the President, Infantry Board, in which he commented, "I note that your tests are conducted under simulated combat conditions. It appears to me that you are using too much simulation and too little combat. Please conduct a study to improve the realism of testing in a combat environment, and to improve testing methodology." As a result of the study initiated by this correspondence, the Infantry Board was later directed by Headquarters, Test and Evaluation Command, to: (1) determine those factors which are critical to the evaluation of infantry weapons in a quasi-tactical environment, and (2) develop techniques and methods for generating meaningful numerical measurements of critical factors on a real-time basis. In support of these objectives, the Board is conducting a 5-year program of experimentation, which has as its immediate purpose: to determine those test factors which must be emphasized; to produce meaningful performance measurements with the smallest possible expenditure of resources; and to determine those test factors which may be de-emphasized or ignored. By determining these, the Infantry Board hopes to be able to reduce sample size and to reduce testing time, while still producing significant results in the evaluation of the man/weapon system.

The accomplishment of the program's purpose is complicated by the fact that each individual--the gunner, the operator, the soldier--becomes an integral part of the weapon system, and therefore neither the weapon nor the operator can be isolated; neither can the man/weapon system be isolated from its environment. The critical test factors being sought, then, can be found only by a total systems evaluation of the man and his weapon, in a combat environment.

Since systems research and evaluation is an iterative process that combines many activities in a series of steps or stages, the Board's process is one of establishing requirements, test design, experimentation and redesign. It is a continuous activity, requiring a continuing search for answers to the following questions:

a. What criteria are most appropriate for evaluation of each portion of the system?

b. How do the system variables/factors relate to the criteria?

c. Of the design components that seem possible and feasible, which factors represent the greatest potential improvements to the entire system?

The criterion most appropriate for evaluation of the man/weapon system is effectiveness of fire; this can be defined as the spatial and temporal distribution of hits over a specified target area. This area may include personnel and vehicular targets, or it may simply be a piece of real estate. The dependent variables applicable to this criterion are time to first hit, number of rounds necessary to achieve first hit, total hits as a function of time, and total time of engagement. In addition, suppressive fire must be measured, because the ability to achieve a near miss which would suppress the actions of the enemy often becomes of extreme importance in the evaluation of effectiveness of fire. Consequently, the dependent variables also include time to first near miss, and patterns of near misses as a function of time. Other measurements which become important in an evaluation of the man/weapon system are time to activate weapon, rate of fire, ammunition load, marksmanship, and individual physical characteristics. The importance of these as evaluators of man/weapon performance varies with the characteristics of the environment, which include such things as the tactical situation, weather, climate, vegetation, and soil composition.

The Board is working with the smallest unit on the battlefield--the rifleman. This has two implications: first because of the density of the rifleman in combat, very small improvements in the man/weapon system may mean very large gains in battlefield effectiveness. An incremental improvement of one in the 4th decimal place is not a significant improvement for a single rifleman; but multiplied across three divisions, it may be extremely influential in terms of enemy attrition, or our own soldier survivability. The second implication is obvious, then. How does one measure very small differences? The answer lies in sensitivity, and resolution. The tools provide the needed sensitivity; the experimental design resolves measured outputs in terms of the design variables.

The necessary tools to undertake such evaluations were not available when the Infantry Board began this study. As often occurs in other undertakings, before a task can be initiated, the tools to do it must be designed. This is the stage of the current effort. The Board is in the process of designing instruments sensitive enough to isolate, and measure, those factors which significantly influence the effectiveness of the man/weapon system. The instruments which provide informational inputs during current firing exercises on the range include an FM-telemetered round-count device with each firer, hardwired shock transducers or photoelectric cells to locate the position of each firer in meters from the target, hit-sensitive targets, and near miss sensors. The time resolution of these different sensors permits the measurement of the performance of each firer, whether alone or in a group. The FM signal, and the position location signal, locate the point of origin of the round. Knowing the point of origin of the round, the time of firing the round, and the time at which the round passes the target area, enables identification, within limits, of the effect of each specific round fired.

Targets are laminated plastic foam and aluminum (layers of plastic--aluminum--plastic--aluminum--plastic) such that the projectile short circuits the two aluminum foils when the target is hit. The short circuit is cleared about a hundred-thousandth of a second later as the bullet completes passage through the target. The pulses generated by the short circuits are recorded at an instrumentation center. A hit on target also causes the target to fall, thereby providing informational feedback to the firer which simulates battle conditions, and enables him to adjust his sight picture or to modify his range estimation. Although the recording system observes very few instances of simultaneous firing, squad members firing on the range frequently do. If two individuals fire on the same target within a second, and one of them scores a hit, both assume they have scored hits, and both will shift fire to another target. This, too, adds to the realism of the battlefield simulation. A target, when hit, will fall, and may be made to rise within the variable cycle time of 2 to 4 seconds.

Location of misses in the target area is now determined by microphones which record the amplitude of the shock wave of each passing round. But the system is being converted to one which will locate such misses mathematically. Miss distances will be calculated on the basis of time differences of the arrival of the shock wave at adjacent transducers.

Shock wave transducers for miss detection are mounted directly behind the targets. A miss will be heard by the transducer behind the target for which it had been aimed, and on the adjacent target transducers as well.

The formula used to locate misses mathematically is reproduced below. If D_0 represents the distance from the bullet path to the target transducer at which the round had been aimed, D_1 the distance to the first transducer to the left, and D_2 the distance to the first transducer to the right, then the general form of the equation is derived from the distance formula:

$$D_0 - D_1 = \sqrt{(X - X_0)^2 + (Y - Y_0)^2} - \sqrt{(X - X_1)^2 + (Y - Y_1)^2}$$

$$Y^2 = AX^2 - BX + C$$

A second equation is produced by the time difference $D_0 - D_2$. These equations are hyperbolic, and, when solved simultaneously, will produce four possible values of X and Y. By judicious selection of origins (X = 0, the leftmost transducer; Y = 0, the ground level), all negative values of X and Y are meaningless, and only the numerical values in the first quadrant are significant. This sometimes provides two values of X and Y, but they differ by orders of magnitude, and the correct set of coordinates is readily discernible.

At the same time that the Infantry Board is designing the tools to measure sensitive factors, it is also in the process of developing experimental designs. Since not enough data have been accumulated on the effects of such things as range distances, firing positions, target configurations, or scoring techniques, which are the most essential and critical parameters of comparative studies, it is necessary to investigate these areas systematically, to determine those experimental variables which should form the basis of small arms tests. All of them patently cannot be examined in a single study, but in a series of consecutive studies it should be possible to identify the critical variables. For example, one firing position may be more critical than all other firing positions when weapons must be evaluated, or a certain range distance, or distances, must inevitably be included whenever one wishes to conduct a comparative evaluation of weapons. Success in the search for those factors which must be emphasized, and those which may be de-emphasized, depends heavily on the ability to develop designs and instrumentation to gather necessary data under meaningful conditions.

Since the establishment of true mathematical relationships among the variables of a combat environment is still far in the future, simulation models are playing an important role in drawing conclusions from measurable situations. The model provides the first estimate of the mathematical relationship between factors.

What are some of the influencing factors? First, the man part of the man/weapon system--the human factors. To what degree do physical attributes relate to combat effectiveness? Marksmanship? Fatigue levels? Ability to estimate range? Next, weapon differences. What comparative differences are inherent in recoil, sights, trajectory, rate of fire, mode of fire, ammunition supply? Then come environmental effects: rain, cold, heat, mud, dust. Furthermore, the rifleman rarely goes it alone. How does the individual squad member react at a specific time to a given set of stimuli? Which controls, weapon mixes, weapon numbers most affect individual man/weapon performance? How does feedback from rounds fired on the objective by other squad members affect individual performance? Additionally, what are the tradeoffs between firepower and accuracy, firepower and the weight to be carried by the individual soldier? The first problem being attacked therefore is to ascertain which are the major factors that influence man/weapon system performance. This requires quantification of the combat environment--a massive undertaking, and one which is only beginning to be developed. But this is the path the Board will follow in seeking answers to the questions above.

Ranges that will provide the basic building blocks for analysis are now in the process of being built. A small arms attack range is already operational; a quick-fire range has been completed and is undergoing testing. Three other ranges--a small arms defense range, an indirect-fire range, and an antitank range--will be constructed during the next 2-year period. Each range has, or will have, instrumentation which records the performance as a function of time, of each round fired, each hit, and each near miss.

There follows a discussion of some of the results of the first test on the attack range--the first range completed--to demonstrate the quantity of data and the degree of resolution thus far achieved. These output data will become the criteria for evaluating the design of later ranges, instrumentation, and experimental design, and will ultimately be used as input to command, control, and organizational studies. Analysis of these results has demonstrated that the ranges can measure significant variables in the performance of the man/weapon system. The results of the first test have been embodied in a report dated April 1966, entitled, Pilot Experiment, Attack Experiment I, Small Arms Service Test Design for a Study of Small Arms Service Test Facilities and Methods. It is emphasized that this experiment was conducted to test the range--not to compare the weapons.

There are two ways of improving test methodology: increase the quantity of data, and increase the quality of data. Figure 1 shows the quantitative increases experienced during the first field experiment. The primary measure of performance on firing ranges in the past has been in terms of the percentage of hits achieved, under specified conditions, measured at the conclusion of an exercise. Under such circumstances, when firing at an attack objective from 150 meters, about 12% of the available data could have been measured. This means that nothing would have been known about 88% of the rounds fired--except that they had been fired. By adding near miss and short round sensors, measurable output data were increased to 97%. The quality of the data is empirically demonstrated in the figures 2 through 6. Figure 2 shows the target hits, by range, for both weapons. These data showed rifle A superior in hit probability at all distances on the range, and superior by a statistically significant difference at 6 out of 17 of the distance increments. Comparison of reacquire times (figure 3) showed little difference between the firing positions tested (supported kneeling and prone), but did uncover a significant difference between the two weapons. Other data supported the conclusion that firers encountered more difficulty in rapid acquisition of a steady sight picture with rifle B.

Figure 4 presents an analysis of the time necessary to change magazines. Here, a small difference, not considered significant, in favor of rifle B was found. In computing the data shown on figure 4, pure magazine change time was identified by subtracting reacquire time from the reloading manipulation. It was found that the time required to reload and to reacquire the target averaged approximately 15 seconds. The Infantry Board considered this excessive, and this experiment became the basis for a Board recommendation to higher headquarters that there be an urgent improvement of the magazine component of current small arms weapons systems.

Figure 5 shows a sample of information produced by combining weapons performance in terms of near misses in the two basic firing positions. The curves indicate superiority of the prone position at longer ranges, but oddly enough favor the kneeling position at closer ranges, possibly due to improved visibility of the higher head position.

Assault fire information (figure 6) displayed for the 88-meter to 40-meter range firings, compared to hits per rounds fired from 150 meters to 88 meters (in the kneeling and prone positions), indicates the degradation of performance during all trials, by all players, as they initiated assault firing. The percentage of hits in the assault is only 5% or lower. Performance in the assault is significantly different from performance in the kneeling and prone positions with both rifles, and it is clear that the technique of using assault fire deserves further analysis.

In summary, as can be seen from the charts, the data base already accumulated in the field experiment permits display of comparative curves of weapons performance, singly or in combination, as affected by <u>any</u> of the independent variables chosen in the experimental design.

These are the building blocks with which we move to the next level of penetration. Each new level achieved in testing procedures provides the stepping stone to higher and more sophisticated plateaus. The COMBATEST concept is an iterative process which has significantly advanced test methodology, and from which has evolved development of test facilities which permit more rapid, and more accurate, evaluation of the man/weapon system.

The Infantry Board is pleased with the progress already made in development of the COMBATEST concept, and the concept has been integrated into Board operations, supporting our motto--ONLY THE BEST FOR THE FINEST.

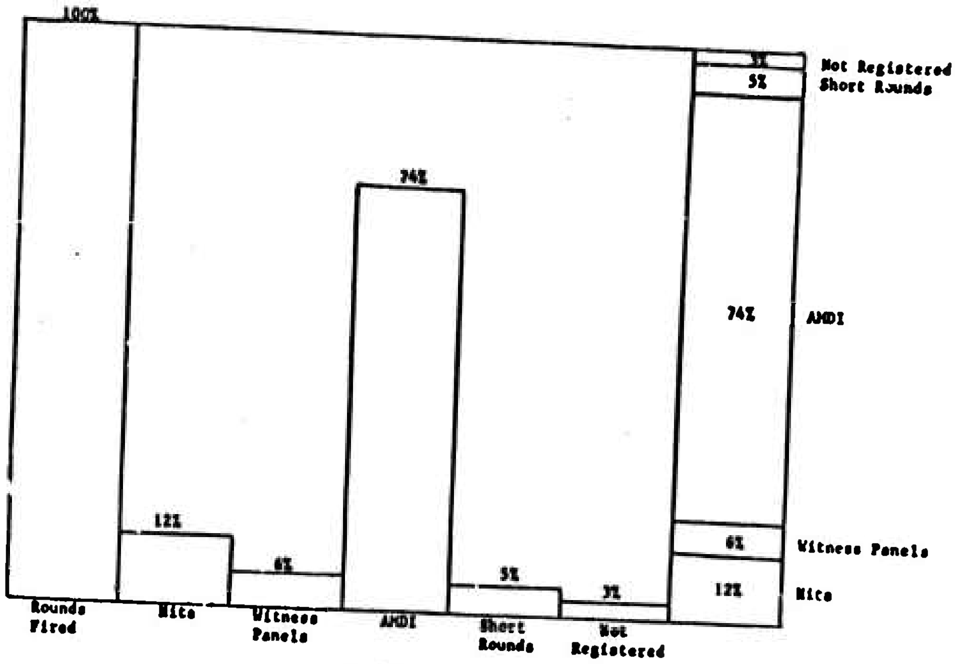

FIGURE 1

PERCENTAGES OF ROUNDS SENSED
BY VARIOUS INSTRUMENTS
RANGE 150 METERS

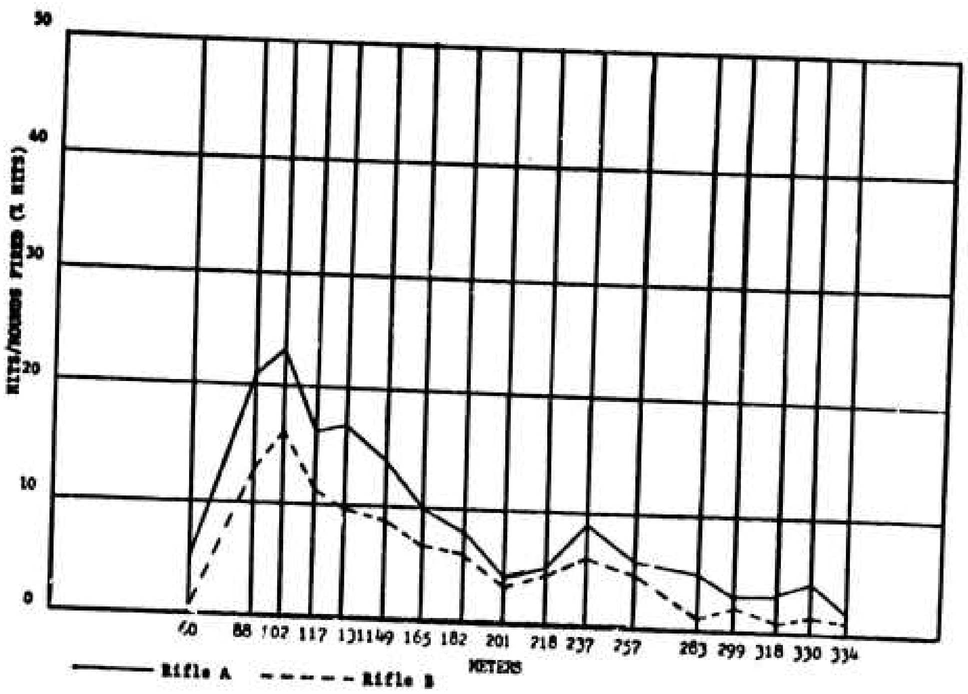

FIGURE 2

PERCENTAGES OF HITS AS A FUNCTION OF RANGE

	Rifle A Kneeling	Rifle A Prone	Rifle B Kneeling	Rifle B Prone
MEAN (SEC)	3.75	4.09	6.07	6.04
S	3.37	3.06	4.01	5.53
Z - SCORE	.45		.0079	
Z - SCORE	2.71			
MEAN (BOTH POS)	Rifle A - 3.92; Rifle B - 6.05			

FIGURE 3

REACQUIRE TIME (SECONDS)

	Kneeling	Prone	Mean (Both Pos)
Rifle A	10.88	11.67	11.26
Rifle B	9.87	10.22	10.05

FIGURE 4

MAGAZINE CHANGE TIMES (SECONDS)

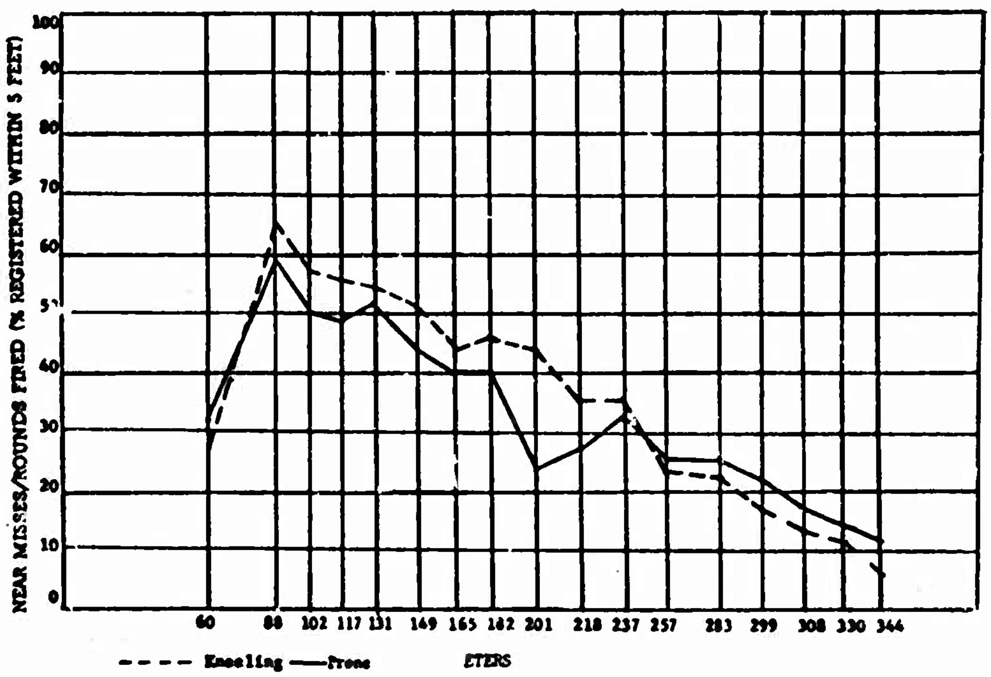

FIGURE 5

PRONE VS KNEELING FOR RIFLE A AND RIFLE B
(NEAR MISSES OVER ROUNDS FIRED)

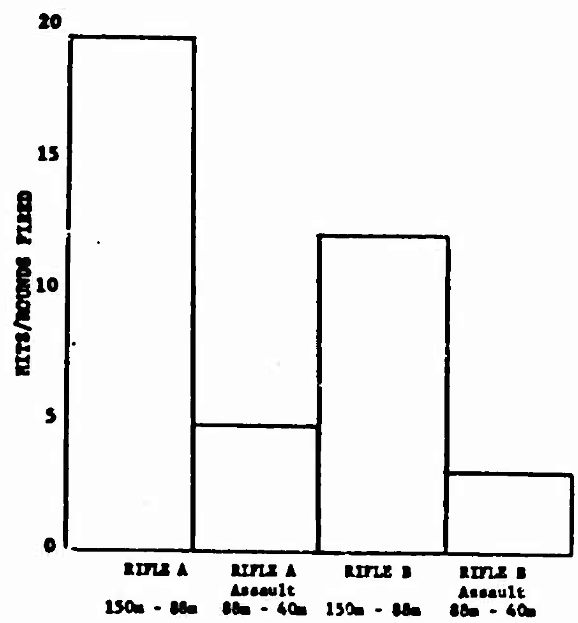

FIGURE 6

PERCENTAGE OF HITS
AT 150m - 86m AND ASSAULT